

Claims 8 - 27 are presently pending in the application. In order to advance the prosecution of the present application, Claim 8 has been amended to recite that the first layer of  $\text{TaN}_x$  and the second layer of Ta together form a combined barrier layer and wetting layer useful in combination with a conductive layer. This amendment should not be construed as agreement with or acquiescence to the Examiner's grounds for rejection of any of the claims in the application. All of the amendments to the claims set forth above are fully supported by the specification and drawings as originally filed.

Both the Specification and the Claims have been amended to correct a formal matter, where the { } bracketing of the crystallographic content lattice numbers has been replaced with < > bracketing, which is recognized in the art as being the more technically correct form of bracketing.

#### Claim Rejections Under 35 USC § 112

Claims 21 - 27 are rejected under 35 USC § 112, first paragraph, as containing subject matter which was not described in the specification in such a way as to enable one skilled in the art to which it pertains, or with which it is most nearly connected, to make and/or use the invention. The Specification has been amended to include the subject matter of Claims 21, 23, and 27, which subject matter was a part of the disclosure in the application as originally filed. Claims 21, 23, and 27 recite that if one skilled in the art follows applicants' method, a Cu <111> crystallographic content of at least 70% will be obtained. This is all that is necessary to enable one skilled in the art to make and/or use the invention. One skilled in the art is able to make a copper interconnect structure (Claim 21) or a copper-comprising via structure (Claims 23 and 27) having a copper crystalline structure which is at least 70 % <111> in content by following the method steps. One skilled in the art will know how to use the interconnect or the contact via, as the use is well established in the art.

The Examiner may be inquiring about how one skilled in the art (or applicants) knows that a crystalline structure having at least 70 % <111> is obtained when the method is followed. There is a direct correlation between the data provided in Figure 2 and the copper <111> content. Applicants provided the intensity and FWHM data combination rather than the calculated copper <111> content, because they believed a one skilled in the art can better see the directional effect of the changing variables from this data, so that it is more meaningful than the copper <111> content which can be calculated based on the data.

Claims 22 and 24 - 26 are rejected as being dependent upon a rejected base claim. Applicants believe these claims are now allowable in view of amendment of the Specification and the above explanation.

The Examiner is respectfully requested to withdraw the rejection of Claims 21 - 27 under 35 USC § 112, first paragraph.

Claims 21 - 27 are rejected under 35 USC § 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention. Claims 21 - 27 include reference to "the barrier layer of Claim 1". Claim 1 has been canceled in response to a Restriction Requirement, thereby rendering the scope of Claims 1 - 27 indefinite. Claims 22 and 24 - 26 are rejected under 35 USC § 112, second paragraph, as being dependent upon a rejected base claim.

In response to the rejection of Claims 21 - 27 under 35 USC § 112, second paragraph, the description of the structure to be obtained has been amended, and the reference to the "barrier layer of Claim 1" has been removed.

In light of the above amendments to Claims 21, 23, and 27, withdrawal of the rejection of Claims 21 - 27 under 35 USC § 112, second paragraph, is respectfully requested.

All of the amendments to the claims set forth above are fully supported by the amended specification, and by the combination of the specification, claims, and drawings as originally filed.

Applicants will now address each of the remaining claim rejections based on cited art, as raised by the Examiner.

Claim Rejections Under 35 USC § 102

Claims 8 - 11, 14, 15, and 17 are rejected under 35 USC § 102(b) as being anticipated by U.S. Patent No. 5,281,485, to Colgan et al.

With respect to the rejection over Colgan et al., the Examiner has noted "...that the preamble recitation of a barrier layer useful in combination with a conductive layer was not given the effect of a limitation in the claim." In order to advance the prosecution of the present application, independent Claim 8 has been amended to make it clear that applicants are claiming a combined structure including a barrier layer and a wetting layer which is used in combination with a conductive layer. The claimed method is for producing a combined barrier layer and wetting layer structure which is used in combination with a conductive layer, wherein the method comprises particular steps. The method is limited to one which produces the specified combined barrier layer and wetting layer structure used in combination with a conductive layer.

Colgan et al. discloses a method of making Alpha-Ta thin films rather than the prior art Beta-Ta thin films. (Abstract, and Col. 1, lines 25 - 30 with Col. 3, lines 60 - 61.) The purpose is to lower the resistivity of the Ta thin film, as illustrated in Figure 2A of Colgan et al. To ensure the formation of Alpha Ta, a seed layer of Ta(N) is deposited on the substrate prior to deposition of the Ta layer. This contrasts with the present invention which relates to a method of forming a three-layer structure including a combined barrier layer and wetting layer structure (Ta/TaN<sub>x</sub>) over which a conductive layer is deposited. Applicants' Claim 8 has been amended to include a step c) in which

the conductive layer is deposited over the Ta wetting layer. Typically, the conductive layer is copper, as claimed in Claim 9. When the conductive layer is copper, the purpose of the invention is, as described in the Summary of the Invention, Page 5, lines 16 - 19, to form a Cu layer having a high  $\langle 111 \rangle$  crystalline content, so that the electromigration resistance of the Cu layer is increased.

① Thus, applicants' method includes the deposition of a conductive layer over the Ta layer, which is neither described or suggested in Colgan et al. When the conductive layer is copper, the copper layer has increased electromigration resistance. This solves a problem pertaining to deposited copper layers which is neither mentioned or contemplated in Colgan et al.

In addition, in forming the Ta(N) seed layer, Colgan et al. discloses at Col. 5, lines 22 - 32, that the doped tantalum seed layer is not the same as depositing Ta<sub>2</sub>N, which requires precise control of the gas composition during the deposition process. This contrasts with applicants' Claim 14, where the x of TaN<sub>x</sub> ranges from about 0.1 to 1.5. In the case of Ta<sub>2</sub>N, applicants' x would be about 0.5. Thus, Colgan et al. teaches away from the present invention in teaching that x is not 0.5 or less.

In light of the above, withdrawal of the rejection of Claims 8 and 9, and claims which depend therefrom, including Claims 10, 11, 14, 15, and 17 under 35 USC § 102(b), as being anticipated by Colgan et al., is respectfully requested.

#### Claim Rejections Under 35 USC § 103

Claims 8 - 17 are rejected under 35 USC § 103(a) as being unpatentable over U.S. Patent No. 5,391,517, to Gelatos et al., in combination with U.S. Patent No. 5,676,587, to Landers et al.

Gelatos et al. discloses a three-layer "interface layer" structure which overlies the surface of a dielectric layer and comprises, from bottom to top, a first titanium layer, a titanium nitride layer, and second titanium layer. (Abstract, lines 9 - 12.) Although Gelatos et al. suggests that other metals having the necessary adhesive and diffusion barrier characteristics can be employed to form the interface layer, the example provided is the use of titanium or tungsten or tantalum in place of

titanium nitride as a diffusion barrier layer, and the use of chrome as the upper metal layer of the interface layer (Col. 3, lines 53 - 60). There is no suggestion of the use of tantalum nitride as the diffusion barrier in combination with an overlying wetting layer of tantalum.

*is not suggested*  
With regard to deposition of an overlying copper layer, there is no suggestion that a copper layer having a high  $\langle 111 \rangle$  crystal orientation be deposited over the interface layer. There is no mention or even a suggestion of using a high  $\langle 111 \rangle$  crystal orientation in the copper layer to reduce electromigration of the copper. Instead, the emphasis is in creating a copper-titanium intermetallic layer to provide adhesion of the copper layer to the underlying titanium nitride layer (Col. 5, lines 14 - 43.) In order to create the copper-titanium intermetallic layer, Gelatos et al. uses an annealing step. The annealing step is carried out at reduced pressure and at a temperature of about 500 °C - 600 °C (Col. 5, lines 26 - 28). In the alternative, Gelatos teaches that annealing may be carried out at a lower temperature of about 400 °C to about 500 °C in the presence of a forming gas (N<sub>2</sub>H<sub>2</sub>) ambient. Applicants do not need to form a copper-tantalum intermetallic layer, and no annealing step is required after copper deposition, unless a copper seed layer is used and annealing of the combination of seed layer with subsequent copper deposition is necessary. Further, applicants have limited amended Claim 8 to require that the maximum temperature of the copper either during deposition or during subsequent processing is less than 500 °C. Applicants previously explained that it is important to maintain the copper at a temperature of 500 °C or less, preferably 300 °C or less, since the crystal orientation of the copper is sensitive to temperature. (Specification, Page 6, lines 14 - 17 and limitations in originally filed Claims 21 - 24 and 26). An annealing step above 500 °C, as recommended by Gelatos et al. would adversely affect the  $\langle 111 \rangle$  content of the deposited copper layer; and therefore, Gelatos et al. teaches away from the present invention.

Landers et al. discloses a chemical mechanical planarization method for selectively removing a layer of metallization material such as tungsten or copper and a liner film such as Ti/TiN or Ta/TaN from the surface of an oxide layer of a semiconductor wafer. At Col. 1, lines 38 - 43, the

"Background Art" section of the Landers et al. patent states: "A thin liner film, generally not more than approximately 1,000 Angstroms thick is then deposited over the oxide layer. The liner generally comprises thin films of titanium (Ti) and titanium nitride (TiN) disposed over one another to form a Ti/TiN stack, or tantalum (Ta) and tantalum nitride (TaN) to form a Ta/TaN stack." This language indicates that Ti is deposited over the oxide layer, and TiN is deposited over the Ti layer; and, that Ta is deposited over the oxide layer, and TaN is deposited over the Ta layer. This corresponds with the Gelatos et al. disclosure which teaches at Col. 3, lines 40 - 50: "In a preferred embodiment, a first titanium layer 16 overlies the surface of dielectric layer 12, and a titanium nitride layer 18 overlies first titanium layer 16. . . . Specifically, titanium nitride layer 18 provides a diffusion barrier preventing the transport of copper into first titanium layer 16 and the underlying dielectric and device layers". By contrast, the present invention is a method for making a TaN<sub>x</sub>/Ta barrier layer. The order of deposition of the tantalum nitride and tantalum is a critical feature of the method of the present invention. As applicants explained in their Summary of the Invention at Page 5, lines 12 - 19, although TaN<sub>x</sub> is a better barrier layer for copper than Ta, copper deposited directly over TaN<sub>x</sub> does not exhibit a sufficiently high degree of Cu <111> crystal orientation to provide the desired copper electromigration characteristics.

Combining the disclosure of Gelatos et al. with the disclosure of Landers et al. does not render obvious the present invention. In fact, this combination of references teaches away from the present invention. For the reasons set forth above, applicants respectfully request withdrawal of the rejection of Claims 8 - 17 under 35 USC § 103(a), over Gelatos et al., in combination with Landers et al.

Claims 8 - 17 and 21 - 26 are rejected under 35 USC § 103(a) as being unpatentable over U.S. Patent No. 4,985,750, to Hoshino, in view of Landers et al.

With regard to the disclosure of Hoshino, the Examiner states the following: "Hoshino teaches a method of producing barrier layer for the subsequent deposition of an overlaying conductive layer.

In reference to Figure 2, a first layer [20] of the barrier layer is deposited by a traditional sputtering method followed by the deposition of a second layer [22], the second layer being a Ta layer having a thickness in the range of 500 to 3000 Å. A conductive layer of copper [24] is then deposited over the barrier layer (Col. 3 lines 28-66)." It is readily apparent that there is a discrepancy in this description, because if a Ta layer is deposited over the barrier layer, then the copper layer subsequently deposited will not be deposited upon the barrier layer. Upon review of Col. 3, lines 28 - 41, of the Hoshino patent, applicants found the following language: "A metallic layer 20 is deposited on the insulating film 18 and on the top of the n<sup>+</sup>-diffused layer 16a in the Si substrate 16 through the contact hole 18a. The metallic layer 20 may be made of Ti, Al or platinum (PT), for example. . . The metallic layer 20 is provided to form an ohmic contact of low resistance with the Si substrate 16. That is, when using Ti, titanium silicide (TiSi<sub>2</sub>) produced by the application of heat makes a low-resistance contact." Upon review of Col. 3, lines 49 - 64, of the Hoshino patent, applicants found the following language: "A barrier metallic layer 22 is deposited on the metallic layer 20. . . . In other words, the barrier layer 22 underlies the Cu metallization layer 24. . . . The barrier layer 22 may be made of titanium nitride (TiN), tungsten (W), tungsten nitride (WN), zirconium nitride (ZrN), titanium carbide (TiC), tungsten carbide (WC), tantalum (Ta), tantalum nitride (Ta<sub>2</sub>N<sub>5</sub>) or titanium tungsten (TiW)." In other words, contrary to the Examiner's assertion, Hoshino's barrier layer is a single-layer, not a two-layer, structure. Either tantalum or tantalum nitride (which are listed as possibilities number 6 and 7 on a laundry list of nine potential barrier layer materials) may be used as the barrier layer. In this case, the Hoshino reference recommends depositing the copper metallization layer directly over a barrier layer of TaN<sub>x</sub>, in contrast with applicants' disclosure which teaches that copper deposited directly over TaN<sub>x</sub> does not provide the desired copper electromigration characteristics. Or, the Hoshino reference recommends depositing the copper metallization layer directly over a barrier layer of Ta which overlies a metallic layer of Ti, Al, or Pt, for example, where the metallic layer is provided to form an ohmic contact of low

resistance with the Si substrate. Copper deposited over Ta which overlies a metal silicide is clearly distinguishable from applicants' copper layer deposited over a controlled thickness of Ta which overlies a TaN<sub>x</sub> barrier layer.

The distinctions between applicants' invention and the disclosure of the Landers et al. reference are discussed above. Both the Landers et al. and the Hoshino references describe the deposition of the copper layer directly over a TaN barrier layer. Combining the disclosure of Hoshino with the disclosure of Landers et al. does not render obvious applicants' invention.

For the reasons set forth above, applicants respectfully request withdrawal of the rejection of Claims 8 - 17 and 21 - 26 under 35 USC § 103(a), over Hoshino, in view of Landers et al.

Claims 8 - 17 are rejected under 35 USC § 103(a) as being unpatentable over U.S. Patent No. 5,240,880, to Hindman et al., in view of either Landers et al. or Hoshino.

Hindman et al. discloses a contact metallization scheme for aluminum. A titanium layer is sputter deposited into a contact hole. The titanium layer reacts with the underlying silicon to form a silicide at the time of sputtering. A titanium nitride layer is sputtered on top of the titanium layer. "Optionally, an additional titanium layer can be formed on top of the titanium nitride layer to clean off the titanium target used to sputter the titanium and titanium nitride layers on the wafer. A metal layer including aluminum is then formed on top of the titanium layer or the titanium nitride layer to form the contact metallization . . .". Hindman also requires the use of a heating step to react some of the titanium in the layer which is in contact with silicon, to produce a silicide layer. Even more importantly, at Col. 4, lines 33 - 38, Hindman et al. makes it clear that use of a layer of titanium overlying the titanium nitride layer is optional. There is no disclosure of any advantage in application of a titanium layer directly underlying the aluminum layer in terms of a benefit to the aluminum layer. In fact, at Col.4, lines 38 - 49, Hindman et al. explains that the additional titanium layer is deposited for purposes of removing nitrogen species from the titanium sputtering target

surface, and that the additional titanium layer does not adversely affect the contact metallization resistance of the junction. There is no suggestion that a titanium layer be applied to directly underlie the aluminum layer as a means of reducing electromigration in the aluminum layer, and no requirement that such a titanium layer have any particular thickness.

First, it is important that the distinction between a titanium/aluminum and a tantalum/copper metallization system be made. There is no disclosure in Hindman et al. related to the use of tantalum or tantalum nitride, and no disclosure related to copper metallization. One skilled in the art will recognize the distinct behavior differences between copper and aluminum and between tantalum used in combination with copper, compared with titanium used in combination with aluminum.

The Hindman et al. disclosure further contrasts with applicants' teachings which clearly require the use of a pure tantalum layer directly underlying a deposited copper layer. Whereas Hindman et al. states that the use of a titanium layer directly underlying the aluminum layer is optional, and is present due to a procedure to remove nitrogen from the sputtering target, applicants require the use of the underlying tantalum layer, so that a high <111> crystal orientation will be obtained in the copper layer deposited over the tantalum layer, to reduce electromigration in the copper layer. Further, Claims 8 - 17, which are rejected in view of Hindman et al. require a tantalum layer having a thickness falling within a particular range. This is necessary so that the desired copper crystal orientation will be obtained without the deposition of excess tantalum which may provide subsequent removal problems (on portions of the substrate surface which are not to be metallized).

As described above, Landers et al. discloses a thin liner film comprising thin films of tantalum (Ta) and tantalum nitride (Ta<sub>2</sub>N<sub>5</sub>) disposed over one another to form a Ta/Ta<sub>2</sub>N<sub>5</sub> stack. The present invention is a method for making a Ta<sub>2</sub>N<sub>5</sub>/Ta barrier layer. As a result, the layer directly underlying the conductive layer is different. Applicants have explained that use of a TaN layer directly underlying a copper layer does not produce the desired copper crystal orientation.

As described above, the Hoshino reference recommends depositing the copper metallization

layer directly over a barrier layer of  $TaN_x$ , in contrast with applicants' disclosure which teaches that copper deposited directly over  $TaN_x$  does not provide the desired copper electromigration characteristics. Or, the Hoshino reference recommends depositing the copper metallization layer directly over a barrier layer of Ta which overlies a metallic layer of Ti, Al, or Pt, for example, where the metallic layer is provided to form an ohmic contact of low resistance with the Si substrate. Copper deposited over Ta which overlies a metal silicide is clearly distinguishable from applicants' copper layer deposited over a controlled thickness of Ta which overlies a  $TaN_x$  barrier layer. Absence of the  $TaN_x$  barrier layer may permit copper diffusion through the metal layers into underlying substrate layers.

Combining the disclosure of Hindman et al. with the disclosure of Landers et al. or Hoshino does not render obvious the present invention. For the reasons set forth above, applicants respectfully request withdrawal of the rejection of Claims 8 - 17 under 35 USC § 103(a), over Hindman et al., in view of either Landers et al. or Hoshino.

Claims 12, 13, and 16 are rejected under 35 USC § 103(a) as being unpatentable over Colgan et al., in view of either Landers et al., Gelatos et al., or Hoshino.

The distinctions between applicants' invention and Colgan, Landers et al., Gelatos et al, and Hoshino are provided above. None of these references individually teaches or even suggests applicants' invention. A combination of these disclosures tends to teach away from applicants' invention rather than rendering the invention obvious.

The Examiner appears to have based his rejections on a hindsight reconstruction of the present invention which relies on picking and choosing select elements from a number of essentially unrelated references, without any of the selected references having provided any motivation to do so. The Examiner is respectfully reminded that this constitutes inappropriate grounds for rejection

An obvious-to-experiment standard is not an acceptable alternative for obviousness. Selective hindsight is no more applicable to the design of experiments than it is to the combination of prior-art teachings. There must be a reason or suggestion in the art for selecting the procedure used, other than the knowledge learned from the applicant's disclosure. (*In re Dow Chemical Co.* 837 F.2d 469, 5 U.S.P.Q. 2d 1529 (Fed. Cir. 1988).) An "obvious-to-try" situation exists when a general disclosure may pique the scientist's curiosity, such that further investigation might be done as a result of the disclosure, but the disclosure itself does not contain a sufficient teaching of how to obtain the desired result or indicate that the claimed result would be obtained if certain directions were pursued. (*In re Eli Lilly & Co.*, 902 F.2d 943, 14 U.S.P.Q. 2d 1741 (Fed.Cir. 1990).)

In the present instance, there is no mention in the references cited that the crystal orientation of the overlying conductive layer is important nor that the thickness of a pure metal layer directly underlying that conductive layer is important. The Examiner is respectfully requested to withdraw the rejection of Claims 12, 13, and 16 under 35 USC § 103(a) as being unpatentable over Colgan et al., in view of either Landers et al., Gelatos et al., or Hoshino.

Claims 18 - 20 are rejected under 35 USC § 103(a) as being unpatentable over Gelatos et al., in combination with Landers et al., as applied to Claims 8 - 17, above, and further in view of U.S. Patent No. 5,707,498, to Ngan. Claims 18 - 20 and 27 are rejected under 35 USC § 103(a) as being unpatentable over Hoshino, in view of Landers et al., as applied to Claims 8 - 17, above, and further in view of Ngan. Claims 18 - 20 are rejected under 35 USC § 103(a) as being unpatentable over Colgan et al., in view of either Landers et al., Gelatos et al., or Hoshino, as applied to Claims 12, 13, and 16, above, and further in view of Ngan.

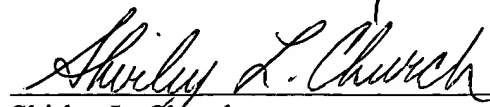
The deficiencies of the disclosures of Gelatos et al., Landers et al., Hoshino, and Colgan et al. with respect to the patentability of the present invention are discussed in detail above.

Ngan discloses ion deposition sputtering of titanium and titanium nitride. Applicants are not claiming that ion deposition sputtering of tantalum or tantalum nitride is unobvious in itself, but rather than the use of the ion deposition sputtering technique in combination with other limitations in Claims 18 - 20 and 27 is nonobvious. There is no suggestion in any of the cited references that ion deposition sputtering be used as a method of deposition for the metal-comprising layers described. Whether taken alone or in combination, none of the references cited above teaches or suggests the presently claimed invention.

For the reasons set forth above, applicants respectfully request withdrawal of the rejections of Claims 18 - 20 under 35 USC § 103(a), over Gelatos et al., in combination with Landers et al., and further in view of Ngan; Claims 18 - 20 and 27 under 35 USC § 103(a), over Hoshino, in view of Landers et al., and further in view of Ngan; and Claims 18 - 20 under 35 USC § 103(a), over Colgan et al., in view of either Landers et al., Gelatos et al., or Hoshino, and further in view of Ngan.

Applicants believe that the claims as amended are in condition for allowance, and the Examiner is respectfully requested to enter the requested amendments and to pass the application to allowance. The Examiner is invited to contact applicants' attorney with any questions or suggestions, at the telephone number provided below.

Respectfully submitted,



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